A COMBUSTION DEVICE

The present invention relates to a combustion device, and more particularly but not exclusively to a combustion device for a gas turbine engine, and furthermore to the assembly of components forming a combustion device. A combustor is commonly used in a gas turbine engine to burn fuel in compressed air to produce exhaust gas for exhaust to a turbine. Recent combustor designs have aimed at reducing emissions of nitrogen oxide (NO) and nitrogen dioxide (NO_2) – collectively known as NOx. Running the combustor to produce well-mixed fuel and air in a mixing channel can decrease NOx emissions. However this level of mixing can create flame instability at low flow rates, leading to flame blow-out. Consequently it is known to use a secondary or pilot fuel inlet to prevent the blow-out occurring. One combustor design has a stub tube having several fuel inlets arranged to admit fuel into a mixing channel to increase mixing and reduce NOx emissions. However, this arrangement is prone to flame instability and potential flame blow-out. A stub tube creates a wake, which reduces the effective area of the mixing channel and reduces the flow rate of air and fuel through the mixing channel. Each of these multiple inlet designs has the problem that each inlet must be calibrated at every position individually. This is time consuming and fiddly, and can also result in costly downtime. An object of the present invention is to relieve the problems of the prior art in a simple and effective manner at no major expense.

Furthermore, radial swirlers for industrial gas turbine combustors typically involve a series of rectangular mixing ducts issuing tangentially into a closed end cylindrical chamber. This arrangement results in the formation of a stable solid body rotation of sufficient strength for the formation of a recirculation zone to provide for flame stability. The highly swirling flow within the chamber also provides for additional mixing. The use of rectangular ducts does however have several disadvantages. The need to achieve a uniform

fuel distribution within each duct for low emission performance can necessitate a complex injection arrangement, such as fuel rods projecting across each duct. The inter duct discharge coefficient may also show some variation, due to slight variations in duct aspect ratio, impacting on mixture uniformity within the combustion chamber. Finally, the use of rectangular ducts dictates certain manufacturing methods which may not be conducive with low cost or ease of production.

Various aspects of the present invention are set out in the independent claims. A number of optional features are set out in the dependent claims. The optional features are applicable to each aspect of the invention and the invention envisages and extends to any combination of the aspects and optional features hereof which is not specifically recited herein.

When an insert channel portion/plug is provided, this may be removably attached to the body, such as by threaded engagement or a push fit, or permanently attached, such as by braising.

According to another aspect of the present invention, there is provided an apparatus for mixing compressed air with fuel, comprising a body having a mixing channel for mixing fuel and air, a primary fuel inlet and a secondary fuel inlet, wherein the secondary fuel inlet is adapted to admit fuel into a zone of separated flow on the body. In a further aspect of the present invention the secondary fuel inlet is positioned outside of the mixing channel. The advantage of this is that a relatively small amount of fuel may be admitted to a zone in which there is little mixing of air and fuel, therefore providing flame stability and avoiding flame blow-out, whilst the majority of fuel is admitted through a primary fuel inlet in the mixing channel to produce a well mixed mixture of air and fuel.

According to another aspect of the invention, the mixing channel has a rectangular cross-section, having a width dimension defined in the axis substantially parallel to the plane of the swirler body, and a depth dimension

defined in the access substantially orthogonal to the plane of the body, wherein the mixing channel aspect ratio is such that its depth-to-width ratio is less than or equal to 2. In yet another aspect of the invention the same depth-to-width is less than or equal to 1.5, preferably $\leq$1.25 or $\leq$1.0. This ratio is preferably $\geq$ 0.7. The aspect ratio may be $\leq$2, $\leq$1.5, $\leq$1.2, $\geq$0.5 and/or $\geq$0.7. This ratio may be from 0.5 and 2, preferably from 0.7 to 1.5, e.g. from 0.8 to 1.2, one example being 1.0. Accordingly, better mixing of the air and fuel is achieved than would be obtained by a taller mixing channel having a higher depth-to-width ratio.

According to a further aspect of the invention the apparatus has a fuel metering means having an elliptic or otherwise curved or partly curved cross-section such as circular, oval or racetrack-shaped. In another aspect of the invention the fuel metering means is removable and may also be of elliptic cross-section.

A number of further optional features, which may be applicable to any one or more of the above aspects of the invention, will now be described.

Preferably, the mixing channel comprises a bore formed in the body of the apparatus, the bore having an elliptical cross-section, which may be circular. The advantage of an elliptic cross-section channel is that fuel may be conveniently admitted into the channel from around the channel, so as to increase mixing of the fuel with air entering the channel, and so the channel flow does not suffer from the reduced effect of area that can occur in the corners of rectangular channel flows.

Preferably, the zone of separated flow is outside of the mixing channel so as to avoid reducing the mixing channel effective area. The secondary fuel inlet is more preferably positioned downstream of the mixing channel. The advantage of this is that air and fuel are well mixed prior to secondary fuel being added, thus minimising NOx emissions, and yet the pilot (or secondary) fuel is available when the mixture is vulnerable to flame blow-out. The body

may be a swirler. The mixing channels may be equi-spaced around the circumference of the swirler, and the secondary fuel inlets may be equi-spaced around the centre of the swirler to facilitate good mixing of air and fuel. In other cases, the secondary fuel inlets may not be equally spaced. Preferably, the secondary fuel inlets are positioned on axes, each axis being aligned with the longitudinal axis of a mixing channel. Hence fuel may be admitted into multiple streams of air and the mixture is able to enter the air/fuel chamber from several directions simultaneously, creating a circumferentially uniform influx of the mixture into the air/fuel chamber. In one aspect of the invention there may be an equal number of secondary fuel inlets and primary fuel inlets, and in another aspect of the invention there may be fewer secondary fuel inlets than there are primary fuel inlets. Preferably, the mixing channels are oriented so as to impart a swirl component of motion to the air/fuel mixture exiting the mixing channels, such that a vortex is formed in the air/fuel chamber producing a low pressure core in the air/fuel chamber flow. The low-pressure core will induce mixture in the air/fuel chamber to recirculate back up the chamber such that any excess fuel in the mixture can be burnt.

The removable means for metering of the fuel preferably comprises a fuel-metering insert. An advantage of a removable fuel metering means is that the means may be calibrated outside of the apparatus and then installed on the apparatus. This is not only more convenient for the calibrator, but also avoids having to stop the apparatus in order to perform the task, reducing costly downtime. Preferably, the fuel-metering insert comprises a bell mouth entrance and a main insert bore, the bell mouth reducing pressure losses as intake air enters the insert. Preferably, the fuel-metering insert is insertable into the mixing channel insert bore and may be threadably insertable (or a push fit) into the mixing channel insert bore for ease of installation and removal thereof.

When installed on to the apparatus, the insert's bell-mouth entrance may define the mixing channel entrance. Preferably, when the insert is installed on the apparatus the mixing channel then comprises the bell mouth entrance through which mixing air enters the insert, the main insert bore, the body channel main bore and exit. Preferably the mixing channel body bore has a cross-section graduating from being elliptical adjacent the mixing channel insert bore to rectangular at the exit, such that the flow exiting the mixing channel is tangential to the body, producing a uniform vortex in the air/fuel chamber. The insert's main bore may comprise an elliptical cross section having a similar cross-section to that of the mixing channel body bore, thus ensuring a smooth transition between the two bore sections. This will allow the air/fuel mixture to flow undisturbed to the channel exit. The elliptical cross-section is preferably a circular cross-section to obtain the advantage already mentioned.

The insert may comprise an opening for the admission of fuel into the main bore of the insert, and the opening may be in fluid communication with a primary fuel manifold. There is preferably a plurality of openings spaced around the perimeter of the fuel-metering insert to facilitate good mixing in the mixing channel. The fuel-metering insert may include an annular manifold in fluid communication with the primary fuel inlet at one end thereof and with the primary fuel manifold at the other end. The opening may be the primary fuel inlet. Preferably the fuel metering means is positioned so that the insert bore is tilted upwards towards the centre of the body.

The air/fuel mixing apparatus is preferably a combustor, which may have a body, an air/fuel chamber, a casing and an exhaust. The casing, body and air/fuel chamber may be adapted so that intake air, preferably from a compressor, flows through the gap between the casing and the air/fuel chamber prior to entering the mixing channel. The body may be a swirler adapted to induce a low-pressure core in the air/fuel chamber. The low-pressure core

caused by the swirler may induce a recirculation zone in the air/fuel chamber. The swirler may include a surface in fluid communication with the air/fuel chamber, the surface preferably having a boundary layer adjacent to it that includes an attached portion and a separated zone downstream of the attached portion. The swirler may comprise a fuel manifold having a primary fuel manifold and a secondary fuel manifold for admission of fuel into the swirler. The fuel may be a fluid, and is more preferably a gas.

According to another aspect of the invention, a method of mixing air and fuel comprises the admitting of fuel through a primary inlet and a secondary inlet into a body, wherein the fuel admitted by a secondary fuel inlet is admitted to a flow separation zone on the body.

According to an alternative aspect of the invention, a method of calibrating a fuel metering means comprises calibration of the fuel metering means and then installation of the fuel metering means on an apparatus for mixing air and fuel.

In a preferred construction, an improved method of fuel injection for a lean, well-mixed system for use in a low NOx combustor is provided in combination with a radial inflow swirler/mixing apparatus, employed for establishing a flame stabilising zone. A preferably movable fuel injector or plug gives advantages over conventional methods in terms of mixing length, flow prediction, ease of calibration, clean aerodynamics and pressure loss. The injector/removable plug/portion of the mixing apparatus is essentially a bell-mouthed air metering orifice of high discharge coefficient, which preferably screws or push-fits into the body of the swirler/mixing apparatus which is preferably of the radial inflow type. The injector is preferably surrounded by a gas fuel gallery from which the fuel is injected into the mixing channel through one or more fuel metering holes. The size and number of the holes may be selected to control the quantity of fuel injected. Mixing of fuel and air may be achieved in a relatively short distance from the point of injection. In contrast,

other conventional injection systems are believed to incorporate stub tubes and wall injectors needing long passage lengths to achieve low standard deviation of mixing and low NOx production in the subsequent flame zone. In addition, these known injectors often upset the aerodynamics and discharge coefficient of the mixing channel, calling for individual calibration and higher pressure losses. Additional benefits from improved injection/mixing of fuel may be the option of selecting a lower combustion zone airflow and therefore wider flame stability margin at a given level of NOx production and the benefit of such a change may be the allocation of more air for cooling other parts of a combustor on which the mixing apparatus may be employed.

The mixing apparatus may be employed for gaseous fuel although applications for liquid fuels are also envisaged.

The present invention will now be explained in more detail by the following non-limiting description of preferred embodiments and with reference to the accompanying drawings, in which:-

Fig.1 is a view through a section of a combustor apparatus according to a first preferred embodiment of the invention;

Fig.2 is a detail of a portion of the apparatus of Fig. 1;

Fig.3 is a plan view of a swirler of the apparatus of Fig. 1;

Fig.4 is a sectional elevation of a combustor apparatus according to a second preferred embodiments of the invention;

Fig.5 is a detail of a portion of the apparatus of Fig. 5;

Fig.6 is a plan view of a swirler of the apparatus of Figs. 4 and 5;

Fig.7A is a cross-section of a mixing channel of the apparatus of Fig. 2;

Fig.7B is a cross-section of a mixing channel according to a modified embodiment of the invention;

Fig.8 is a sectional elevation of a combustor apparatus according to another embodiment of the invention;

Fig.9 is a detail of parts of the apparatus of Fig. 8;

Fig.10 shows a sectioned plan view and a side view of a swirler of the apparatus of Fig. 8;

Fig.11 shows a fuel metering means of the apparatus of Fig. 8.

Fig.12 shows a partial perspective cross section through the swirler plate of the embodiment of Figs. 8 to 11;

Fig.13 is a schematic view showing the various combustors in accordance with the embodiments of the present invention which may be incorporated in a gas turbine engine;

Fig.14 shows a modified secondary/pilot inlet system, having an annular recess and ring;

Fig.15 is a cross-section through mixing channels of a swirler plate of a further embodiment of a combustor in accordance with the invention;

Fig.16 shows the swirler plate of Fig.15 secured on a combustion liner and with back plates for secondary fuel inlets and an ignitor secured thereto;

Figs.17A to 17D show a modification of the embodiment of Fig.1 in which secondary/pilot fuel inlets are shielded;

Figs.18A to 18H show a different modification to the embodiment of Fig.1 in which a radial pilot/secondary fuel arrangement is provided; and

Figs.19A to 19C show a modification to the embodiment of Fig.16 in which fully circular mixing ducts are used issuing tangentially into a toroidal chamber.

Fig.1 shows a sectional elevation through a combustor in accordance with the invention. The combustor 1 comprises a casing 2, a liner (or combustion chamber) 4, a fuel manifold 6 and an exhaust 8. The casing consists of an outer casing 10 having an internal insulation 12, and a top flange 14. The casing 10 is generally cylindrical with a rectangular shape in side section. The combustion chamber 4 comprises a pre-chamber 16 expanding to the main chamber 18. At an end of the combustion chamber opposite the pre-chamber 16 is a contraction 20 that narrows to an exhaust 8. The fuel manifold

6 comprises a swirler 22, fixedly attached to the top flange 14 by one or more clamping studs 24 as shown in Fig.2.

Fig.1 and Fig.3 show the swirler 22. In the embodiment described, the swirler 22 consists of a circular plate 23 although other shapes may be used. Fig.3 shows a plan view of the swirler 22. The swirler comprises an outer annulus 34 inside of which is located generally triangular wedge sections 36. The wedge sections 36 are, in the present embodiment, of a generally wedged shape, having a longer side 42 and two shorter sides 38 and 44 in which a shorter side 38 is curved to the same curvature as an inner circumference of 35 the annulus 34. The wedge sections 36 are fixedly attached to the annulus 34 at the curved side 38, and arranged inside the annulus 34 so as to form channels 40 between the straight longer side 42 of one wedge 36 and the straight shorter side 44 of another. The channels 40 are thus inclined at an angle to the swirler radius such that the longitudinal axis of a channel 40 does not pass through the origin of the circular swirler 22. The channels 40 may be substantially straight or they may be curved. The channels 40 exit into the pre-chamber 16. Ignitor 31 is positioned off-centre as in Fig.8, although it may appear central when viewed from certain directions e.g. Fig.4. The ignitor 31 is off-centre since this will be cooler than a central location.

A primary fuel inlet 46 for admission of fuel into a channel 40 is positioned upstream of the channel 40 although it may be positioned inside the channel, preferably towards the annulus than towards the channel exit 48 as defined by the dashed circular line in Fig. 3. A secondary fuel inlet 50 for further admission of fuel is located outside of the channel just beyond the exit 48. In this embodiment, there is a secondary fuel inlet for every primary fuel inlet. The primary fuel inlets 46 and secondary fuel inlets 50 are located along the longitudinal axes of the channels 40 although they could be positioned off axis. Fig.1 shows a primary fuel connection 30 and a secondary fuel connection 32 that are adapted to admit fuel into the swirler 22. From Fig.2 it is seen that

the primary fuel connection 30 is located within the top flange 14 such that it may be accessed at one end 31. Its other end is in fluid communication with a primary fuel distributor 52, which in turn is also in fluid communication with the primary fuel inlet 46. A plurality of fuel distributor seals 54 surround the primary fuel distributor 52. The primary fuel connection 30, distributor 52 and inlet 46 are aligned with each other in the present embodiment and are positioned upstream of the channel 40.

A secondary fuel connection 32 is located within the top flange 14 such that it may be accessed at one end 33. Its other end 37 is in fluid communication with the secondary fuel distributor 58 which in turn is also in fluid communication with the secondary fuel inlet 50. A plurality of fuel distributor seals 54 surround the secondary fuel distributor 58. A secondary fuel connection 32, distributor 58 and inlet 50 are aligned with each other in the present embodiment and are positioned downstream of the channel exit 48.

The wedge sections 36 each have a through-bore 29 extending through the plate such that clamping studs 24 may extend there through. Each clamping stud 24 holds together the swirler 22, top flange 14 and a flange 60 of the air/fuel chamber or liner 4. Each clamping stud is inserted through a bore 61 in the flange 60, then into the swirler bore 29 before it is inserted into the top flange 14. A nut 62 locks the clamping stud in place.

The mixing channel cross section may be as in Fig 7A or Fig 7B. The ratio of mixing channel height L along the combustor axis to width W may in preferred embodiments be such that L/W is more than or equal to 0.7 and less than or equal to 2.

According to a second embodiment of the invention, as shown in Figs.4 to 6, the secondary fuel inlets 50 are positioned further downstream of the channel 40 and there are fewer secondary fuel inlets 50 than there are primary fuel inlets 46. The secondary fuel inlets are placed so as to admit fuel into a zone of separated flow 65 at the swirler wall 64 adjacent the pre-chamber 16.

The secondary fuel connection 32 and secondary fuel distributor 58 are also positioned in alignment with the secondary fuel inlets 50. Thus the secondary fuel inlets are positioned closer to the point of ignition 31 as shown in Fig.4.

During operation of the gas turbine engine, compressed air enters the combustor 1 through a gap 11 between the internal insulation 12 of the casing 10 and the liner or combustion chamber 4. The mixing airflow path as shown by the arrows in Fig.1 and Fig.4 passes through the gap towards the top flange 14, near which it then enters the channel 40. Fuel is added to the air via primary fuel inlet 46 in a predetermined and precalibrated amount so as to produce a well-mixed mixture of air and fuel in the mixing channel 40. A boundary layer 13 forms at the mixing channel walls (Fig. 7A). The air/fuel mixture flows through the channel exit and enters the pre-chamber 16. Upon immediately exiting the channel 40, the boundary layer remains attached to a swirler/pre-chamber surface (or back plate) 64. The orientation of the channels 40 imparts a swirl motion to the mixture, causing the flow exiting the channels to form a vortex as it is drawn into the pre-chamber 16. As the vortex is formed, the boundary layer at the surface 64 separates, creating a separation zone 65 on the surface 64. The secondary fuel inlet 50 is placed outside of the channel 40 so as to provide a pilot to avoid flame blow-out. In some embodiments of the invention the secondary fuel inlet 60 is placed in the separation zone 65. It is believed that little mixing of air and fuel takes place in the separation zone hence the zone may have a stable flame that is far less likely to blow out than the flame of the well mixed air/fuel mixture. The introduction of secondary fuel at this region 65 also acts as a pilot to reduce the chance of flame blow-out elsewhere in the pre-chamber.

As the vortex forms in the liner (or combustion chamber) 4 a low-pressure region is formed at the vortex core. A portion of the flow at the vortex is induced into the core such that flow reverses direction at the central axis of the vortex near to the swirler. Thus any excess fuel that was not burnt at the

separation zone 65 is returned to the flame front at the point of ignition 60 to be burnt. The remaining air/fuel mixture flows through the liner or combustion chamber 4 in the vortex and is exhausted to a turbine.

The channels 40 may be of rectangular cross-section and may have an aspect ratio as shown in Fig.7A, in which the channel height (L) 66 to width (W) 68 ratio is 1.25 to 1. However another embodiment of the invention the channel height 66′ to width 68′ ratio is less than or equal to 1.0 as shown in Fig.7B. Figs.7A and 7B are views along the longitudinal axis of the mixing channel. These low aspect ratios enable good mixing since fuel may be injected substantially right across the channel to the wall opposite inlet 46.

A further embodiment of the invention is shown in Figs.8 to 11. Fig.11 shows a schematic of a fuel-metering insert 100. The insert 100 comprises an annular plug of elliptical cross-section, and preferably of circular cross-section. The insert 100 has a bell-mouth flange 110 at one end thereof. The flange protrudes outwardly away from the longitudinal axis 112 and defines a bell-mouth entrance 113. The bore wall 114 (Fig. 9) has a threaded section 118 around its peripheral surface 120. In the remaining section of the bore wall 114 is an opening 122 (Fig. 11) providing a through-bore from the inner wall 117 to the outer wall 120 of the bore wall 114. In the present embodiment there are four such openings. The fuel-metering insert 100 is, insertable in and removable from the air/fuel mixing apparatus 1. The channel 40 includes an inlet 125. In this embodiment of the invention the channel 40 includes a portion 130 at the inlet end thereof, which is threaded according to the opposite of the insert threaded portion 118. The fuel-metering insert 100 is threadably insertable into the channel inlet 124. The channel 40 is profiled substantially according to the female of the male insert outer surface 120 profile such that a close fit between the two components is ensured upon threadably inserting the insert 100 into the channel 40 of the air/fuel mixing apparatus 1. The insert is removed by unscrewing the insert from the channel 40. The insert openings

122 may thus be calibrated for fuel admission in a convenient manner whilst the insert is removed from the apparatus. Whilst it is removed, another calibrated insert may replace it, allowing the continued use of the apparatus and minimising the downtime during which the apparatus cannot be used.

The fuel metering insert 100, through-bore 116 and the channel 40 have identical cross-sections at the junction between them, and once installed on the apparatus, the bore 116 is in exact fluid communication with the channel 40. Thus the channel section downstream of the insert in this embodiment of the invention is elliptical, preferably circular in accordance with the cross-section of the insert through-bore 116. The channel 40 may be elliptical at the junction with the inserts 100 and graduates to a generally rectangular cross-section at the channel exit 48.

The openings 122 are, at the insert outer surface 120, in fluid communication with an annular fuel manifold 125, which is in turn into fluid communication with the primary fuel distributor 52. Manifold sealing ring 54 surrounds the primary fuel distributor 52. Manifold 125 is shown in further detail in Fig. 12

The installed insert is tilted upwards towards the fuel manifold, such that the channel 40 subsequently bends to be integral with the generally horizontal plane of the swirler upstream of the channel exits 48.

In use, gas fuel is administered into the air/fuel mixing apparatus through the primary and secondary fuel connections 30,32. Fuel from the primary fuel connection passes through the primary fuel distributor 52 from which it enters the annular fuel manifold 125. Fuel spreads throughout the annular manifold 125 and enters the insert through-bore 116 at the openings 122. Inner insert seal 121 and outer insert seal 123 ensure that fuel does not escape from the insert other than via openings 122. Meanwhile air from the compressor flows through the gap between the casing 10 and the air/fuel chamber 4 and enters the insert bell-mouth entrance 113 where it passes

through the bell-mouth and into the through-bore. Mixing of air and fuel occurs in the through-bore 116 and channels 40 before the mixture exits the channels. Secondary fuel may be added, as with embodiments 1 and 2, before the mixture enters the pre-chamber in the same manner as therein described. Secondary manifold it is preferred that the majority of fuel entering the swirler 22 is admitted via primary fuel inlet 46 and that a much smaller amount of fuel is admitted via secondary fuel inlet 50. As shown for example in Fig.9 the secondary inlet 50 is configured at an angle to inject fuel with a component along the back wall 150 of the swirler. This component is aligned with a corresponding mixing channel's direction and central axis. This allows the secondary or pilot fuel to remain near the back wall as a source of rich mixture which assists in preventing unwanted flame out. As shown by dotted lines in Figs.9 and 10A, one or more of the secondary inlets 50 may (in addition to or as an alternative to having the angled configuration) be provided by a shield 152 having an outlet 154 facing away from a co-operating mixing channel 40, the shield 152 thus conforming to an exit direction of the channel 40. The shield serves to improve resistance to unwanted flame out and is useful for hot starts. The shield may be welded in position or cast as part of the back wall 260. In one embodiment four shielded pilots (secondary inlets 50) are used out of a total of eight pilots. As a further alternative the back wall 260 may be provided with a recessed ring for all pilots, e.g. all eight pilots when eight are used, as indicated schematically in Fig.14 in which an annular ring 160 coaxial with the swirler central axis 162 is fitted in the region of eight secondary, pilot inlets which are located in an annular recess 164. This provides a radially inward flow of pilot fuel along the back wall 260.

The fuel is a fluid, most preferably a gas such as propane or natural gas. However, it may be a liquid such as diesel.

Figure 13 shows schematically the configuration of the combustor 1 in a gas turbine engine 200 having a main air compressor 202 connected to a shaft

204 to a turbine 206 and an alternator 208. A gas boost compressor 210 is provided between gas fuel 212 and the combustor 1. The compressor 202 is fed by an air inlet 214, and the turbine exhausts 2 and exhaust conduit 216. The gas turbine engine may be recuperated in a known way.

Figs.15 and 16 show a revised version of the embodiment of Figs.8 to 12. As shown by the cross-sectional view of Fig.15, eight mixing channels 40 are shown in a swirler casting 200. The mixing panels each have an upstream circular section 202 merging into a rectangular downstream section 204. Inserted into the entrance 206 of each mixing channel 40 is a bell-mouthed circular insert 208 having four primary inlets for fuel 210 spaced equally around the inside thereof, three of which are shown in the cross-sectional view of Fig.16. The primary inlets 210 of the eight mixing channels 40 are connected via manifold channels 212, cross-sections of which are shown in Fig.15, the manifold channels 212 being supplied by a supply port 214, shown schematically in Fig.16. A secondary or pilot fuel supply plate 216 and a further back plate 218 are fixed to the swirler casting 200 by bolts 220. One of several secondary fuel inlets 222 is shown schematically in Fig.16, this secondary fuel inlet having an angled injection conduit 224 like the one shown in Fig.9. In addition to or alternatively to this, one or more secondary inlets may be provided with a shield or may be located in an annular ring-type shield. An off-centre ignitor 228 is secured in position on the back plate 218. The back plate 216 includes a fuel supply gallery/manifold (not shown) for the various secondary/pilot fuel inlets 222. The swirler casting 200, back plate 216 and back plate 218 effectively replace the top flange 14 and swirler 22 shown in Fig.8 and Fig.16 shows how these components are fitted on the liner 4. In the embodiment of Figs.15 and 16, the mixing channels 40 and the bell-mouthed inserts 208 are arranged perpendicular to the central axis of the swirler 200 and this can be contrasted with the arrangement in Fig.8 in which the mixing channel inlets are tilted. However, in other embodiments, it is

envisaged that a cast swirler plate like the one shown in Figs.15 and 16 could have tilted mixing channel inlets.

The secondary inlets may be arranged for proportionate or on/off flow. In one embodiment, when secondary inlets are on, 70% of flow may be through primary inlets and 30% through secondary inlets for pilot fuel, although this may be variable and may be different in other embodiments such as a 60:40 split.

As shown in Fig.17A to 17E, the swirler 22 may be replaced with a swirler 322 in which each or some of the secondary fuel inlets are shielded by shields 300, perspective and cross-sectional views of each shield 300 being shown in Figs.17D and 17E respectively. In the embodiment shown, eight secondary/pilot fuel inlets 350 are provided, with four of the inlets 350 being shielded by shields 300. Each shield is aligned with an axis of a corresponding mixing channel 340 with a shield fuel exit aperture 350 facing away from the direction of incoming flow through the corresponding mixing channel 340.

Figs.18A to 18H show a different modification to the swirler 22 of Fig.1. In this case, the swirler 422 is modified as shown in Figs.18G and 18H by providing a deflector plate 424 over a series of eight pilot outlets 450. Eight pilot outlets 450 are provided. The deflector plate 424 is circular as shown in Figs.18E and 18D. The plate 424 is provided with a slight lip 426 which provides a gap between outlets 450 and a rear face 428 of the plate 424. The deflector plate forces pilot flow radially inwards towards the center of the swirler 422. A possible extension to this arrangement is to provide one or more relief holes in the plate 424 so that pilot flow is split between radial and axially fuel flow to achieve best performance. In this case, a small relief hole may be drilled or otherwise provided through the plate 424 at each location axial aligned with or near to one or more or all of the secondary/pilot fuel outlets 450. The shields 300 or deflector plate 424 provide improved performance and a stable flame.

Figs.19A to 19C show a modification to the embodiment of Fig.16 in which completely circularly cylindrical mixing channels 500 are provided. The circular mixing channels or premixing ducts 500 exit tangentially into a toroidal space 502. The mixing channels 500 can readily accommodate bell mouth shaped entrances 504 like the bell mouth shown in Fig.16. For clarity, the bell mouth inserts are shown removed from Fig.19A but in practice would be similar to those shown in Fig.16. The schematic views of Figs.19D and 19C show bell mouths 504. Curved lines 506 in Fig.19B indicate the line of contact 508 between circular mixing channels 500 and toroidal surface 510, lines 507 schematically providing a similar impression in side elevation in Fig.19C. Circular ducts 500 can be manufactured by simple drilling and reaming operations. Fuel placement is easier in a circular duct than a rectangular duct due to the absence of corners where excessive fuel can get trapped. The toroidal geometry provided by the surface 510 provides a smooth transition from circular premix channels 500 into toroidal chamber 510. The swirling flow generated in the toroidal chamber 510 is then accelerated into a cylindrical pre-chamber 516. The toroidal chamber prevents significant flow separations and recirculations at the duct/chamber interface and therefore prevents unsteadiness in the bulk swirling flow within the chamber 510/516 and unsteadiness leading to the generation of unacceptable combustion oscillations and possible flashbacks, as well as the presence dead-zone-induced auto-ignition as fuel trapped within such regions may experience excessively long residence times.

The swirler block 522 incorporates eight channels 500, although 10 or 12 may also be used or other numbers if desired. Each duct issues tangentially into the toroidal shaped chamber 510 which essentially has part-toroidal side surfaces 512 a flat back surface 514 and an open exit 518 leading into the chamber 516. Each premixing channel 500 incorporates a bell mouth 504 so that a repeatable discharge coefficient can be achieved across all of the

channels 500 to ensure an even flow distribution. Located in each bell mouth are either three or four equi-spaced fuel injection points to provide for a uniform injection of fuel into the premix duct, although the number of injection points may be varied. The injection points are preferably equi-spaced peripherally around the bell mouth, as in the embodiment of Fig.16. The height of the toroidal chamber is set to be equal to the diameter of the premix ducts so that a smooth transition from duct 500 to chamber 510 is achieved without flow separation. The arrangement of tangential ducts and toroid chamber results in the formation of a stable swirling motion within the chamber 510. The swirling motion is sufficiently strong that a recirculation zone is established within the combustor to provide a stabilising mechanism for the flame. The swirling flow accelerates out of the toroidal chamber 510 into the cylindrical pre-chamber 516 prior to issuing into the main combustor. Accordingly, it will be appreciated that the swirler plate 522 may essentially replace the equivalent plate shown in Fig.16 in the overall combustor arrangement. A shielded or radial deflector arrangement may be used as desired with the embodiment shown in Figs.19A to 19C.

Various modifications may be made to the embodiments described without departing from the scope of the invention as defined by the following claims, as interpreted under patent law.